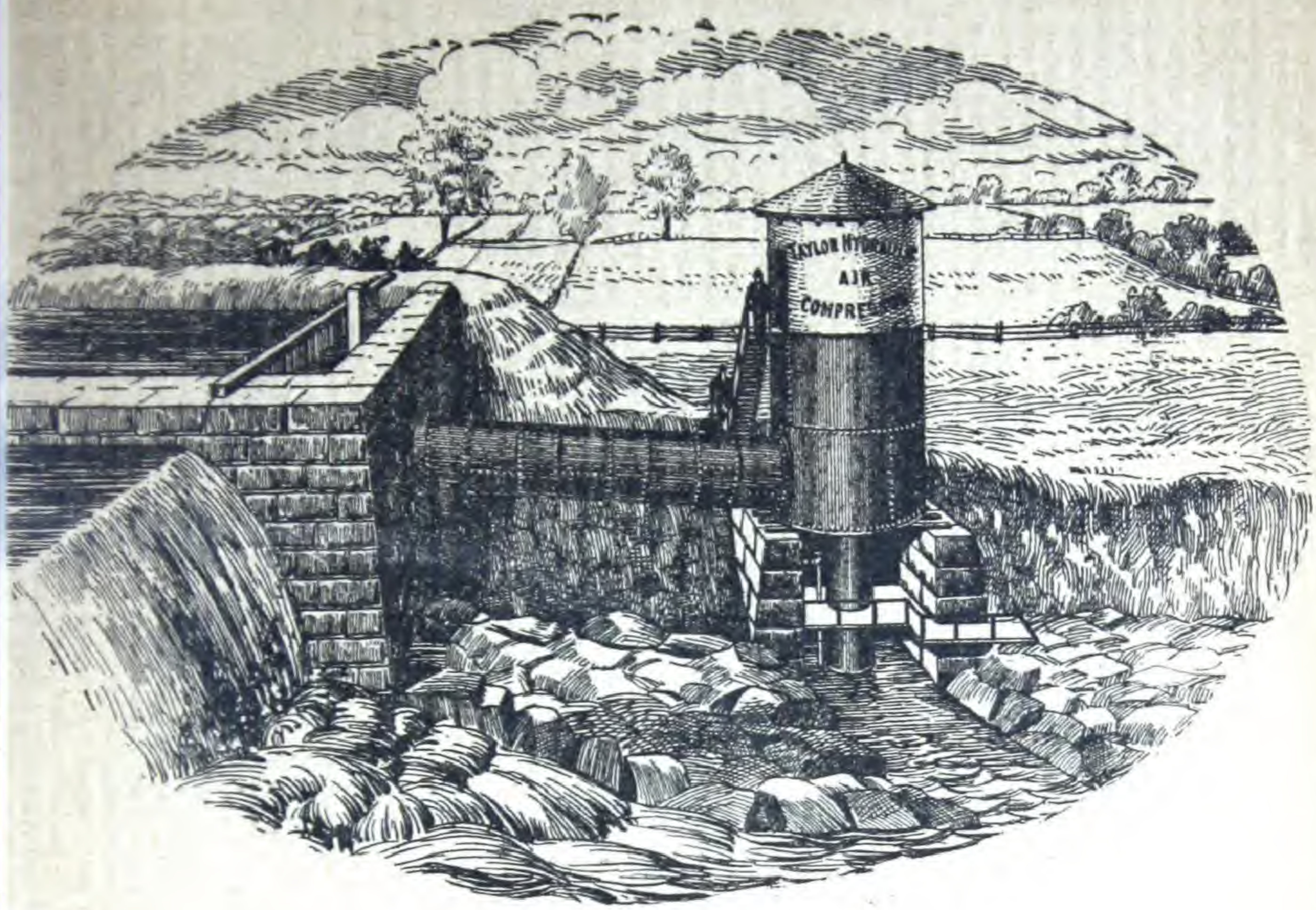


HYDRAULIC POWER TRANSMISSION BY COMPRESSED AIR

ILLUSTRATED DESCRIPTION

—OF—

THE TAYLOR HYDRAULIC AIR COMPRESSOR

—AND—

TRANSMISSION OF POWER

—BY—

COMPRESSED AIR.

TAYLOR HYDRAULIC AIR COMPRESSING CO.

LIMITED,

258 ST. JAMES STREET, MONTREAL, QUE.

View of the Taylor Hydraulic Air Compressor at Magog, Que.

COMPRESSED AIR.

The ever increasing demand for less expensive modes of developing and transmitting power has led to the use of compressed air, which is an exceedingly convenient, economical, and safe form for the transmission and distribution of energy.

Heretofore the use of compressed air has been retarded because it involved for its generation the employment of complicated and delicately adjusted machinery, always liable to derangement; because it necessitated highly skilled labor; and because continual repairs and loss of time very materially advanced its cost, especially where water power was utilized for compression. Freed from these drawbacks, however, there is no more economical form of power than compressed air.

By means of the Taylor Hydraulic Air Compressor the cost of transforming water power into compressed air has been reduced to a minimum. Its advantages are as follows:—

1. It transforms a water power of any head into compressed air of any desired pressure without the usual intermediate losses.

2. Low heads of water, which would otherwise be useless for the production of power, can be used to advantage by this compressor.

3. The air is compressed at a constant temperature, viz.—that of the water, and is consequently delivered at a temperature generally below that at which it is taken into the compressor. Hence there is no loss of power by contraction in volume.

4. The air during compression is freed by the water of the greater part of its moisture, it being delivered so dry that it is impossible for condensation to take place during either its transmission or subsequent expansion. (See page 10 for further information).

Condensation and freezing of moisture in mains, etc., one of the chief obstacles to the use of compressed air, is entirely overcome by this method of hydraulic compression.

5. This compressor will maintain a constant pressure, even under a fluctuating head, without change of efficiency.

6. The compressor is entirely automatic in its action.

7. Owing to the absence of moving machinery the duration of a plant is almost without limit.

8. The absence of moving machinery dispenses with skilled labor, as practically no attendance is required.

9. When the compressed air is not used at the same rate as it is generated, it accumulates and may afterwards give, for a limited time, as much as double the average power developed by the compressor, without change of pressure. This storage of power is effected by displacement of water, and not by an increase of pressure. (See page 14 for further information).

10. A plant does not require to be covered by a building.

THE USES OF COMPRESSED AIR.

There is no limit to the utilization of compressed air for mechanical purposes. It will drive any engine which can be driven by steam, and under proper conditions gives much less trouble. All the attendance that is necessary for an engine using compressed air is to fill the lubricators and open or shut the throttle valve as required. There is no burning out of packing, nor trouble from water condensed in the cylinder. It can be applied more readily than steam to driving machines situated at some distance from the power source. Where steam is transmitted any distance condensation occurs, to a greater or less degree, causing serious loss of power. Air does not suffer any loss in this respect.

IN MACHINE SHOPS.—In large machine shops compressed air has, for this reason, a decided advantage over steam for driving the numerous and varied machines, stationary and moveable, such as pneumatic hoists, hammers, jacks, riveting machines, etc.

IN MINES.—In all well regulated mines compressed air is indispensible for elevating, hoisting, drilling, pumping, and tramcars, the exhaust air serving also to supply the operatives with fresh cool air. Heretofore the expense of generating compressed air have been its chief drawback. The frequency and cost of repairs to cylinder compressors, and the difficulty as well as cost of transportation to and from inaccessible places, has, in many cases, prohibited its use. Mines are usually situated at no great distance from water power, where there could be installed a Hydraulic Air Compressor which entails *no expense for operation*. Mines, which in the past have yielded little or no profit with hand work and cylinder compressors, may be worked at a considerable profit by using this system of hydraulic compression.

FOR STREET CARS.—Air may be stored in reservoirs and used for the propulsion of street cars. A car, so propelled, can run on any surface track by itself or in connection with any other system. It requires no trolleys nor cables, no subterranean nor overhead construction. Compressed air furnishes a motive power for street cars at less cost both for installation and operation than cable, trolley, conduit-electric, storage battery, or any other system. One of the greatest costs of operating cable, trolley and conduit systems is the expense of running the cable and feeding the wires during hours when there is little or no traffic. With compressed air the power is used only when actually needed, as all power stands still, except on cars actually in operation. Each car carries its own power, hence the street blockade, and necessary waste of power in connection with it, is largely avoided.

FOR REFRIGERATION.—After the air has furnished power to an engine, it is, if not preheated, exhausted at from 10° to 25° Fahr. It may, without extra cost, be turned to further use for making ice, for cold storage, or for lowering the temperature and furnishing fresh cool air to overheated workrooms of factories during the summer.

DESCRIPTION OF THE HYDRAULIC AIR COMPRESSOR.

The annexed perspective drawing shows a complete compressor, its details being as follows :—

A. Penstock, or water supply pipe.

B. Receiving tank for water.

C. Compressing pipe.

D. Air chamber and separating tank.

E. Shaft, or well, for return water. (The required pressure is proportional to the depth of the water in this shaft.)

F. Tailrace for discharge water.

G. Timbering to support earth.

H. Blow-off pipe.

I. Compressed air main.

J. Head piece, consisting of—

  a. Telescoping pipe, with

  b. Bell-mouth casting opening upwards.

  c. Cylindrical and conoidal casting.

  d. Vertical air supply pipes. (Each pipe has at its lower end a number of smaller air inlet pipes branching from it towards the centre of the compressing pipe.)

  e. Adjusting screws for varying the area of water inlet.

  f. Hand-wheel and screw for raising the whole head piece.

K. Disperser.

L. Apron.

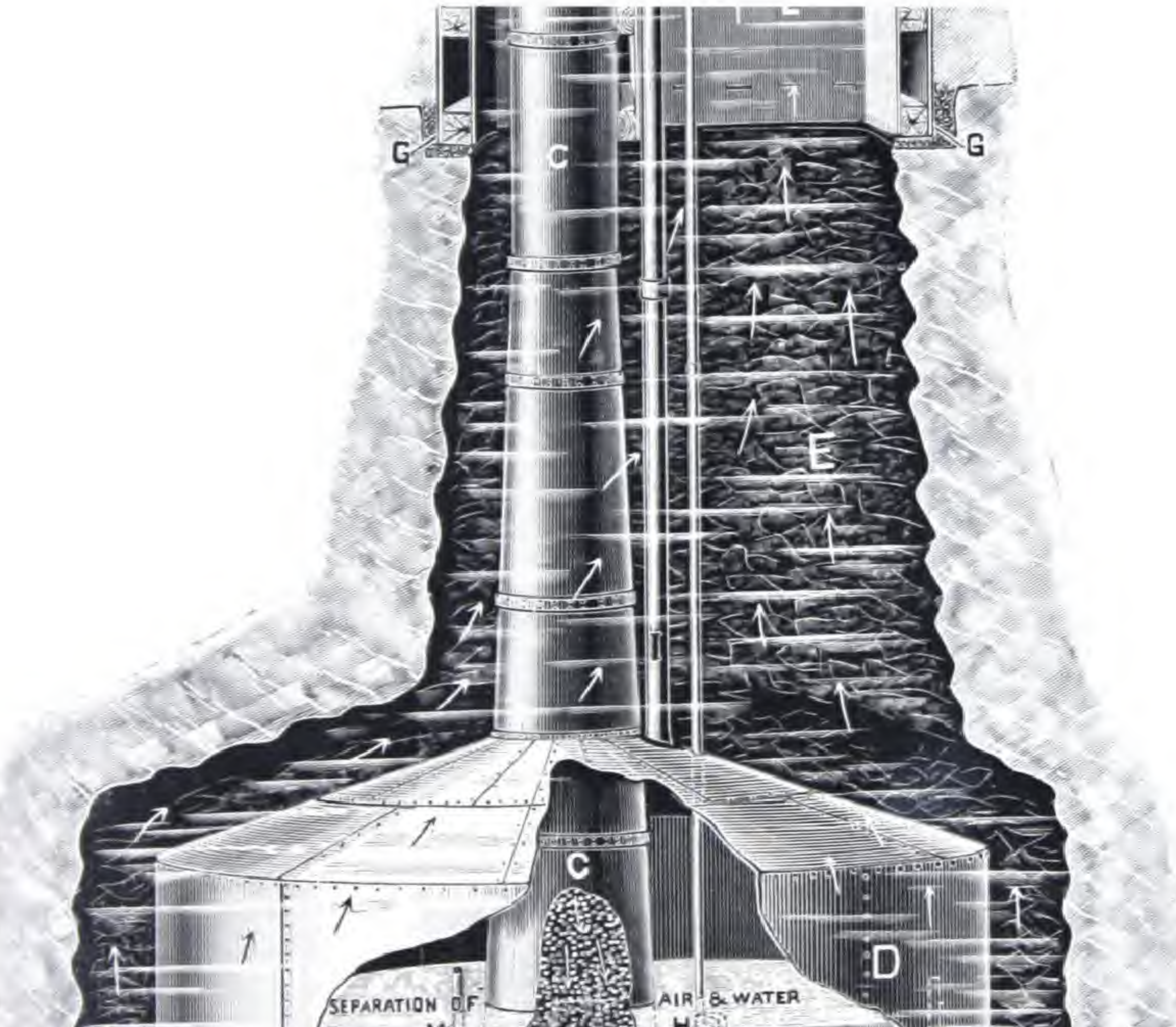
M. Pipes to allow of the escape of air from beneath apron and disperser.

N. Legs by which the separating tank is raised above the bottom of the shaft to allow of egress of water.

P. Automatic regulating valve.

WORKING OF THE COMPRESSOR.

The water is conveyed to the tank B through the penstock A, where it rises to the same level as the source of supply. In order to start the compressor the head piece J must be lowered by means of the hand-wheel *f* so that the water may be admitted between the two castings *b* and *c*. The supply of water to the compressor, and consequently the quantity of compressed air obtained, is governed by the depth to which the head piece is lowered into the water. The water enters the compressing pipe between the two castings *b* and *c*, passing among, and in the same direction as, the small air inlet pipes. A partial vacuum is created by the water at the ends of these small pipes, and hence atmospheric pressure drives the air into the water in innumerable small bubbles, which are carried by the water down the compressing pipe C. During their downward course with the water the bubbles are compressed, the final pressure being proportional to the column of return water sustained in the shaft E and tailrace F. The accompanying diagram shows the relative sizes of the bubbles as they descend in a compressing pipe 116 feet in length.

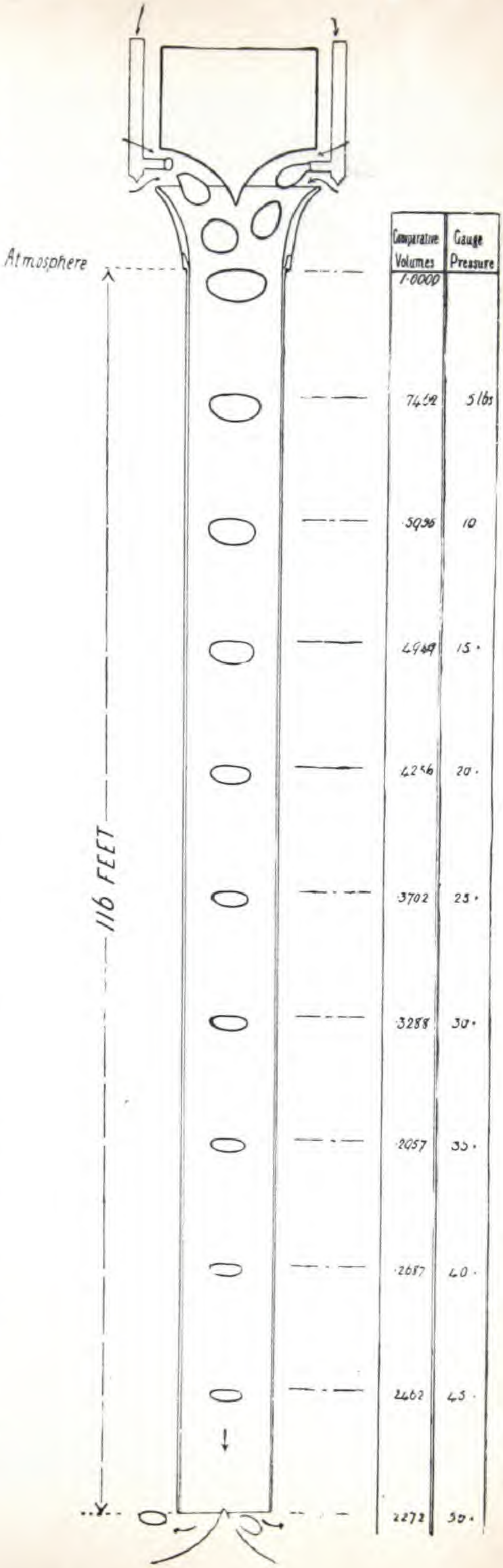


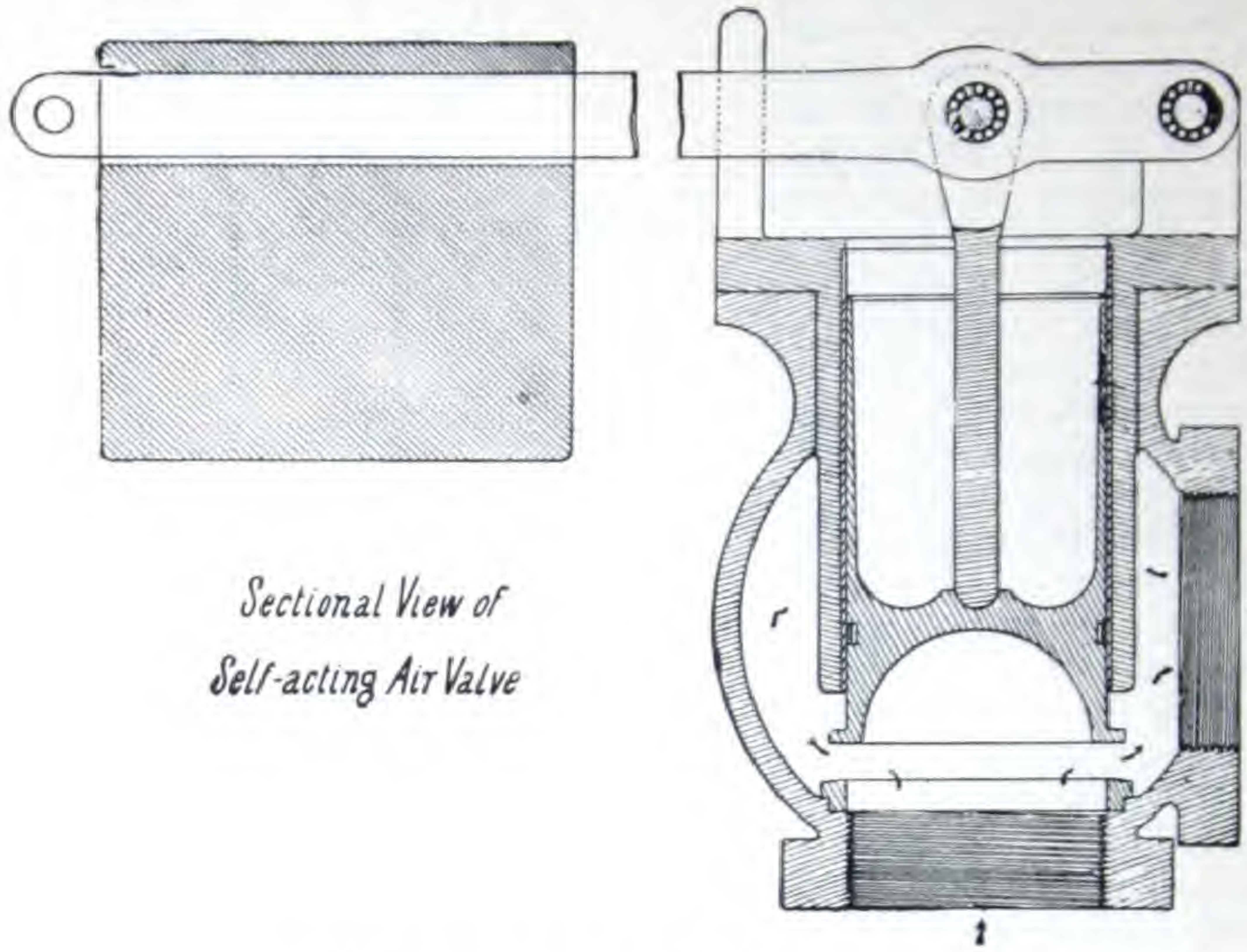
G
G
C
E
C
D
SEPARATION OF
AIR & WATER
M
H
K
K
K
M
L
N
N

When they reach the disperser K, their direction of motion is changed, along with that of the water, from the vertical to the horizontal. The disperser directs the mixed water and air towards the circumference of the separating tank D. Its direction is again changed towards the centre by the apron L. From thence the water flows outward, and, free of air, passes under the lower edge of the separating tank. During this process of travel in the separating tank, which is slow compared with the motion in the compressing pipe C, the air by its buoyancy has been rising through the water and pipes M, M, from under the apron and disperser, to the top of the air chamber D, where it displaces the water. The air in the chamber is kept under a nearly uniform pressure by the weight of the return water in the shaft and tailrace.

The air is conveyed through the main I up the shaft to an automatic regulating valve, and from thence to the engines, etc. The air pressure in the main and air chamber increases 1 lb. per sq. inch for each 2 ft. 3½ in. that the water is displaced downwards in the air chamber by the accumulating air. The variation in pressure from this source will not be more than 3 lbs. per sq. inch in a working plant. As the automatic valve requires a change of only 1 lb. per sq. inch pressure to close it completely, it will be evident that, by properly adjusting the valve, some air can always be retained in the air chamber, and that the water can be prevented from ever reaching the inlet to the air main. If a large quantity of air has accumulated in the chamber, the valve allows of its free passage along the main; but when the air is being used more quickly than it is accumulating, and the pressure decreases below a certain point because the chamber is nearly emptied of air, the valve shuts partially, or completely, adjusting itself to the supply from the compressor.

When the air has displaced the water almost to the lower end of the compressing pipe, it escapes through the blow-off pipe H.





Sectional View of
Self-acting Air Valve

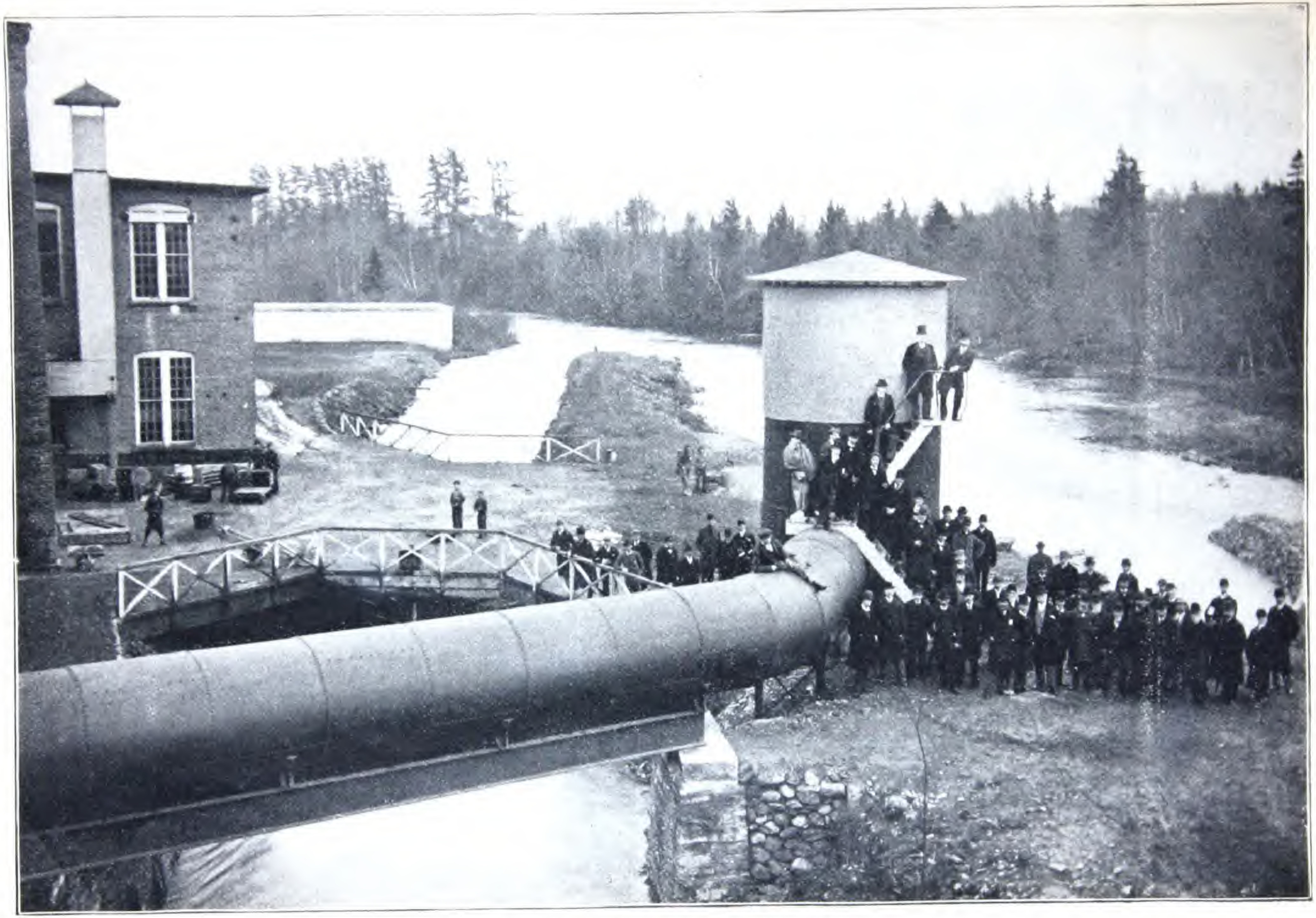
THE MAGOG COMPRESSOR.

The first Hydraulic Air Compressor was installed for the Dominion Cotton Mills Company, limited, to furnish power for their print works at Magog, Quebec.

Printing operations necessitate a great variation in the speed of the machines, the engines, from which they derive power, running at any number of revolutions between 20 and 300 per minute. These conditions cannot be quickly and successfully attained by combinations of pulleys. Each machine must, therefore, have its own engine, since two, or more, machines running at different and varying speeds cannot readily derive power from the same main shaft.

The cotton mill proper uses water power; while the printing machines had been driven by steam. Two attempts, both of which were unsuccessful, had been made by a well known firm, to utilize the surplus power from one of the turbines to produce compressed air for the engines of these printing machines. In the first instance, there was installed a duplex compressor (cylinders 16″ x 24″), which was supposed to be quite large enough to supply the air necessary to drive *four* printing machines. This it utterly failed to do. Next the diameter of the compressor cylinders was enlarged to 20″ x 24″. Again it failed to supply enough air, and the turbine, the surplus power derivable from which was estimated at 300 H. P., was overloaded, seriously interfering with the other work being done by it. In the attempt to supply sufficient air, these compressors were driven at such a speed that it was impossible to keep the journals cool, even with the large quantity of oil used. The demands made upon the second compressor resulted in the termination of its usefulness in less than two weeks.

The installation of the present Hydraulic Air Compressor was attended with much prejudice and no little opposition from several engineers of rather high standing. On account of the previous experiences with cylinder compressors, it was with difficulty also



East View of Magog Compressor.

that the Dominion Cotton Mills Co. was induced to give the Hydraulic Air Compressor a trial. The success attained by this plant has, however, convinced all those who doubted the feasibility of the invention. According to tests made on the 7th. and 13th. Aug., 1896, by Prof. C. H. McLeod, Ma. E., of McGill University, this compressor gives 62 p. c. of the actual power of the water used, and delivers over 155 H. P. in compressed air. This efficiency is secured in spite of the fact that 20 p. c. of the air is lost because of inefficient separation. This defect is due to the separating chamber being a little too small, a condition easily guarded against in other plants. In future an efficiency of not less than 75 p. c. may be counted upon.

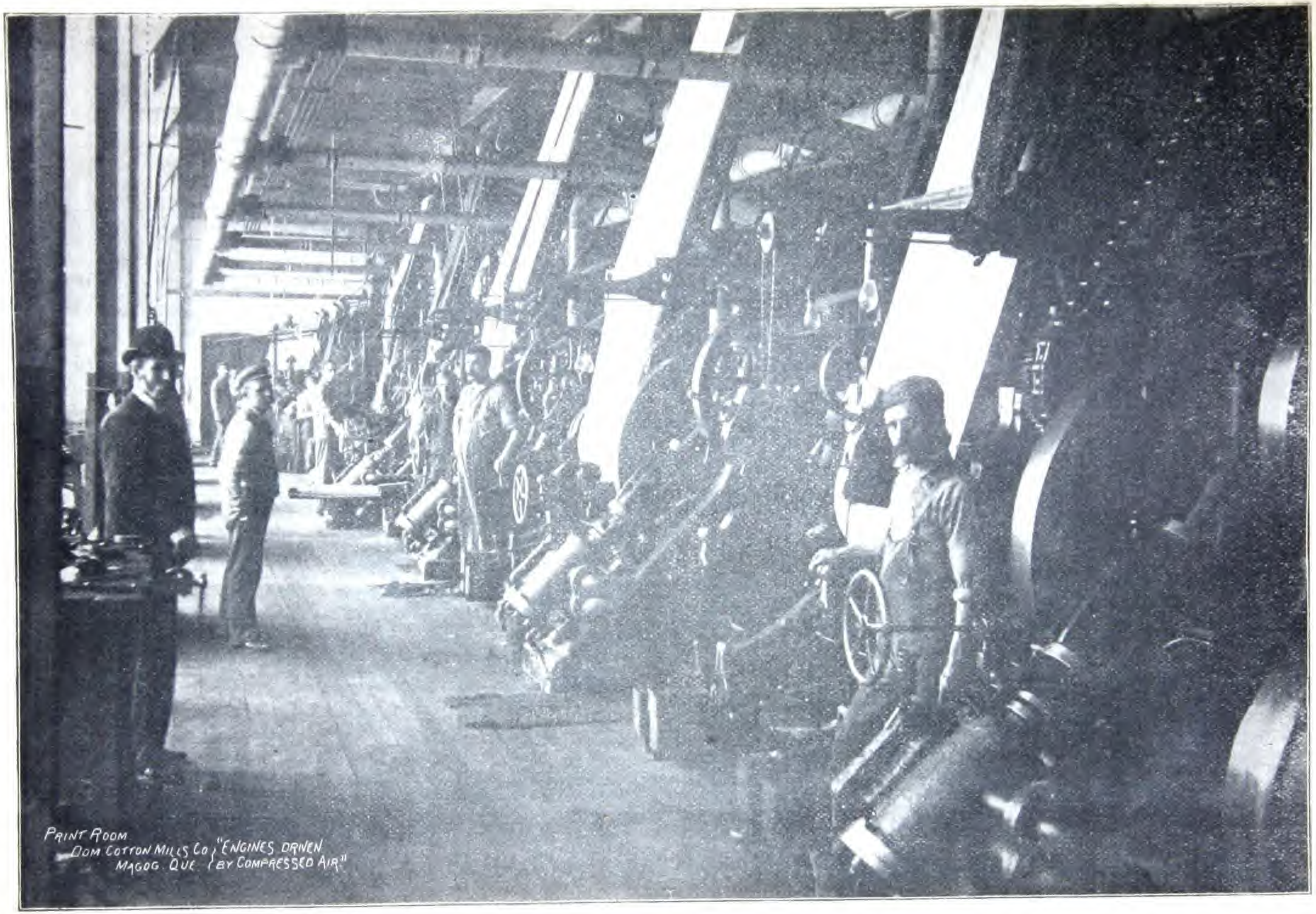
The air was first used in the engines on the 12th Aug., 1896, and since that date, it has provided power as required for seven printing machines, each of which is driven by a pair of engines with 8 in. x 12 in. cylinders. It also furnishes power at night for the feed pumps of the boilers, the machine shop, and other purposes. The air pressure, uniform at all times whether supplying one or more engines, is 52 lbs. per sq. inch. The compressor requires no attention other than starting and stopping it.

MOISTURE CONTAINED BY AIR BEFORE AND AFTER COMPRESSION.

As before mentioned, one of the chief obstacles to the use of compressed air HAS BEEN the condensation of water vapour from the air. It is a well known fact that water vapor may be condensed by a fall in temperature, and also by an increase in pressure. The atmosphere holds varying amounts of water vapor depending almost wholly on its temperature. At 75 degrees Fahr. 1 cubic foot of air can hold 10 grains of water vapor. Under average conditions it holds 7 or 8. Suppose 1 cubic foot of air to be compressed from atmospheric pressure (14.7 lbs. per sq. inch.) to 100 lbs. gauge pressure. The volume of the air and vapor will be reduced to 1/8 (about.) The temperature of the air rises during compression. The effect of the rise of temperature upon the vapor contained in the air, when no cooling device is used, exceeds the effect of the increase in pressure and no condensation takes place during compression. But the air must, during transmission, lose heat and return to about the same temperature as before compression. Consequently from 3/4 to 7/8 of the vapor will be condensed, because one cubic foot at the higher temperature holds eight times as much vapor as one cubic foot of the atmosphere. Hence the water will constantly collect in the air mains, and in cold weather will freeze and obstruct the passage of air.

During short transmission the air may not suffer a great fall in temperature, and may carry the larger portion of the vapor with it to the engines, etc. But the sudden and considerable fall in temperature, caused by the air expanding against the resistance of the piston, is sufficient not only to condense, but also to freeze the moisture in the cylinder and exhaust ports of the engine. This is a continual source of trouble in many instances where the air has been compressed by cylinder compressors.

An attempt is made, with only partial success, to overcome this difficulty by having a large receiver where the air may cool down and deposit its moisture after compression and before it is used. If, also, the mains are well protected, freezing, and much of the


PRINT ROOM
DOM COTTON MILLS CO { "ENGINES DRIVEN
MAGOG QUE. { BY COMPRESSED AIR."

condensation will be prevented. The above device, however, will not, in most cases, free the air of moisture sufficiently to ensure absence of freezing in the engines, when there is no preheating.

In the Hydraulic Air Compressor a bubble of air, while passing down the compressing pipe, is kept cool by the body of water surrounding it. The process of compression is comparatively slow, occupying from 15 to 25 seconds. The temperature of the water is scarcely affected by the heat which it receives from the air during compression (the heat required to raise 1 cubic foot of water from one temperature to any other being about 3,500 times as much as that necessary to produce the same change of temperature with 1 cubic foot of air). The bubble of air is compressed at a constant temperature (i. e. isothermally,) the temperature being that of the water, and the excess of moisture, caused by the gradually increasing pressure, is deposited on the walls of the bubble. Thus it is evident that the air is collected in the separating tank at the low temperature of the water and as dry as it is possible to obtain it. By a test made by Prof. C. H. McLeod, Ma. E., of McGill University, on 50 cubic feet of air hydraulically compressed to 52 lbs. gauge pressure, it was found that the expanded air contained only $\frac{1}{5}$ of the vapor usually contained in the atmosphere during fine weather (or 14 per cent. of saturation). This test was made while the compressor was delivering through the main 1,500 cubic feet of air per minute.

On March 20 and 21, 1897, a pair of 7 in. x 10 in. engines were run, under a full load, by the air delivered direct from the compressor, without preheating, for 40 hours continuously, without showing any sign of a moisture deposit on the interior of the exhaust.

At the same time the considerable fall in temperature from the expanding air was such as to produce, by condensation of the atmospheric moisture, a heavy coating of ice on the *outside* of the exhaust pipe.

THE MOST ECONOMICAL PRESSURE FOR AIR.

The best pressure, consistent with economy, depends upon the distance the air has to be transmitted, and also upon the use to which it is to be applied.

Low Pressures are applicable when the water supply is situated at no great distance (say, under one mile) from the place where the power is to be applied. The most economical pressure, under these circumstances, is from 30 to 75 lbs. per sq. inch, according to the head of water. A low pressure is rather more efficient with a low head.

The Hydraulic Air Compressor differs from cylinder compressors in that it takes in a greater volume of free air when it has to deliver it at a low pressure, and a less volume where the pressure required is greater. If a compressor is installed to furnish a stated power to an engine adapted to the use of air, it is more economical to use the 30-lb. pressure with a large area of piston, than a higher pressure with a smaller piston area. The increased cost of the cylinder and piston (the only parts which would vary in size) would, for the lower pressure, amount to only a small fraction of the increased cost of construction of the compressor for the higher pressure. For example, an engine with a $14\frac{11}{16}$ inch piston, working economically under an air pressure of 30 lbs. per sq. inch, will give the same brake horse power as another with a 12 inch piston working

under 60 lbs. pressure. It must be remembered that the diameter of the cylinder and piston of the first engine are the only dimensions which require to differ materially from those of the second engine, as the mean effective pressure on the piston-rod is the same in both cases.

PRESSURES BETWEEN 75 AND 250 LBS. PER SQ. INCH.—In order to transmit compressed air, distances varying from 5 to 25 miles, the pressure necessary ranges from 75 to 250 lbs. per sq. inch. The conditions to be considered in transmitting a stated power are, the size of pipe, the pressure, and the velocity of transmission. The air may be used to better advantage at low pressure; but the advantage gained thereby is more than counterbalanced by the additional cost of the larger pipe for low pressures. The transmission velocity is an important factor, since at high velocities there is a considerable loss of energy on account of pipe friction. This loss increases rapidly as the size of pipe diminishes. Where the water power is abundant, the loss in pressure, due to pipe friction, may not require to be considered in comparison with the saving in cost effected by using the smaller pipe. Power is not proportional to pressure, since a drop in pressure from 250 to 100 lbs. per sq. inch, caused by pipe friction or throttling, entails a loss of only 29 p. c. of the power of the air. This statement may appear to be an exaggeration, but it is easily understood from the following: 15.6 cubic feet of free air compresses to 2 cubic feet at a pressure of 100 lbs. per square inch, or to 1 cubic foot at 215 lbs. 2 cubic feet of air per second at the lower pressure represents 123.4 H. P.; 1 cubic foot per second at the higher pressure, 165.3 H. P. This shows a drop in power of 25.3 per cent. from 215 lbs. to 100 lbs. per square inch. See pages 18, 19 and 20.

For long transmission, high pressure has, for reasons to be specified, some very decided advantages over low pressure. For example, consider the two cases of air transmitted through pipes of equal diameters, at a velocity of 20 feet per second, under pressures of 100 and 215 lbs. per sq. inch respectively (the absolute pressure in the second case being double that in the first). At 215 lbs. the air is compressed to half the volume at 100 lbs., so that double the quantity of free air is transmitted under the former as under the latter pressure. The power transmitted under the high pressure is $2\frac{4}{9}$ times that transmitted under the low pressure. The percentage loss of pressure from pipe friction does not differ sensibly in the two cases, being less than 2 p.c. per mile for pipes of 9 inches diameter. At 215 lbs. the loss in power is less than 0.8 p.c. for one mile. Again, for a transmission speed of 30 feet per second the percentage loss of pressure per mile, for a 9 inch pipe, is 5.7 p.c.; at 215 lbs., the loss of power for one mile is not over 1.5 p.c.

It is not desirable to transmit compressed air under much higher pressure than 250 lbs. per sq. inch, as high pressures require specially constructed and more expensive pipe, and the loss from leakage will be considerable. Where pressures of 1000 lbs. per sq. inch, and upwards, are required, (as, for example, on street cars or for storage,) it is advisable to transmit a lower pressure (250 lbs.) to a central station where a small portion of the air may be used to further compress the balance to the desired pressure. It is easily estimated that the compressing cylinder capacity in a plant required to compress from 250 to 2000 lbs. per sq. inch would be only one-eighth the capacity necessary when the compression is to be effected from atmospheric pressure upwards.

THE STORING OF POWER IN THE SHAPE OF COMPRESSED AIR.

The Taylor Hydraulic Air Compressor provides a simple means of storing the energy derived from water power. A constant flow of water through a compressor will give a constant supply of compressed air. If this air is used to drive an engine which in turn provides power for saw mills, factories, etc., where the power is used intermittently, the engine will use no more air than is necessary to keep it in motion while doing no useful work, the surplus air provided by the compressor meantime accumulating in the separating tank. It is evident, therefore, that if the air is used for half, or less than half, the time (as is frequently the case) a 100 H. P. water fall may drive engines using as high as 200 H. P. or more. The storing of power in this way does not necessitate a fluctutation in pressure, since it is effected by displacing the water in the separating tank of the compressor.

REHEATING COMPRESSED AIR.

If air at 35° Fah. is heated at a constant pressure, its volume will be increased $\frac{1}{495}$ for each degree over 35°. At 350° F., therefore, its volume will be $1\frac{315}{495}$ of its volume at 35°; and at 400° F., it will be $1\frac{365}{495}$.

To ascertain what will be the increase in volume between any other temperature (e. g. 65° F.) and 350° F., it is only necessary to compare the volume of one cubic foot of air heated from 35° F. to each of those temperatures. For 65° F., it is $1\frac{30}{495}$ (or, $\frac{525}{495}$); and for 350° F., it is $1\frac{315}{495}$ (or, $\frac{810}{495}$). Comparing these ($\frac{810}{495} \div \frac{525}{495} = \frac{810}{525} = 1\frac{285}{525}$), there is obtained the increase ($\frac{285}{525}$) in volume between 65° and 350° F. See Table, pages 16 and 17.

The power of compressed air is increased proportionately as its volume is increased by heating. There is no limit to the additional power which may be imparted to compressed air by raising its temperature; but the practical limit is reached at about 400° Fah., since over that temperature the heat will seriously injure the motor. The reheating of air, and resultant increase of power, may be effected with a trifling consumption of coal compared with the consumption necessary to secure an equal power from steam.

Reheating is accomplished by two methods:—by passing the air through a spiral coil pipe above a furnace fire;—by passing the air through water in a boiler or tank where the water is kept at a temperature which varies according to the pressure employed.

THE REHEATER.—Professor Nicolson, of McGill University, in a paper read before the Canadian Society of Civil Engineers, makes the following statements regarding the reheating of compressed air by the first method. "Without preheating, one horse power in a distant steam engine was found to give 0.61 H. P. on the motor brake. With preheating to 400° Fah., 1 H. P. was obtained. Hence, 0.39 H. P. is obtained by an additional expenditure of 0.3 pounds of coal, or 0.3 ÷ 0.39 = 0.77 pounds of coal per horse power per hour.

"It has long been the custom in Paris to use a small stove, through which the compressed air is passed before being used in the motor. For a 1 horse power motor the air can be heated from 60° to 400° Fah. at an expenditure of 0.44 pounds of coke screenings per hour; while for a 40 horse power motor the preheater will only require 0.22 pounds of fuel per horse power per hour."

Moist Heating.—With regard to the second method, the following is quoted from H. Haupt, consulting engineer of the General Compressed Air Company of New York:—"Air, before being utilized in the cylinders of a motor of any description, is, or ought to be, passed through a tank of water at a temperature at which steam is ordinarily used in a boiler, preferably at about 350° Fah. Each 50 cubic feet of free air is found to absorb about one pound of water in the form of steam. The volume of one pound of steam at atmospheric tension is 26 cubic feet. Hence the steam adds more than 50 per cent. to the volume of the air admitted into the motor cylinder. But the air itself, by increase of temperature, is also expanded more than 50 per cent. This expansion, with the addition of steam, increases the volume more than 100 per cent., or, in other words, by the simple process of re-heating, less than one-half the weight of air will do the work that would be performed if the air were used cold and dry.

"The cost of this re-heating is trifling; the coal required to re-heat and secure double efficiency is less than one-eighth the coal required at the air compressor, (Cylinder compressors are here referred to.)

"The Rome air motor, when the water was twice re-heated, ran 14 miles on a consumption of 308 cubic feet of free air per mile. When the air was not re-heated the consumption of air per mile was 661 cubic feet. This fact is conclusive as to the efficiency of re-heating."

METHOD FOR FINDING THE QUANTITY OF WATER REQUIRED TO DEVELOP ANY DESIRED HORSE POWER OF AIR FROM A HYDRAULIC COMPRESSOR.

	H. P. of air required being 75 p.c. of required water power, of Compressor efficiency 75 p.c.	Add 33⅓ p.c. in all cases.	H. P. of water required.	Multiply by foot-pounds work per sec. in 1 H. P.	Foot-pounds of work per second required.	Divide by head of water in feet.	Lbs. of water per second required under given head.	Divide by weight of 1 cubic foot of water.	Cubic feet of water required per second.
Example.	100	$+ 33\frac{1}{3}$	$= 133\frac{1}{3}$	$\times 550$	$= 73333\frac{1}{3}$	$\div 25$	$= 2933\frac{1}{3}$	$\div 62.4$	$= 47$

TABLE SHOWING PERCENTAGE OF INCREASE IN VOLUME FOR RISE OF TEMPERATURE (FAHR).

The percentage increase in volume, when air is heated at constant pressure from a *lower* to a *higher* temperature, will be found in the same column as the *higher* temperature (given in the top line of the Table), and in the same horizontal line as the *lower* temperature (given in either the right or left hand columns).

Temperature	40°	50°	60°	70°	80°	90°	100°	110°	120°	130°	140°	150°	160°	170°	180°	190°	200°	210°	220°	230°	240°	Temperature
30°	2.04	4 08	6.12	8.16	10.2	12.24	14.28	16.32	18.36	20.4	22.45	24.49	26.53	28.57	30.61	32.65	34.69	36.73	38.77	40.81	42.85	30°
40°	0	2.	4.	6.	8.	10.	12.	14.	16.	18.	20.	22.	24.	26.	28.	30.	32.	34.	36.	38.	40.	40°
50°		0	1.96	3.92	5.88	7.84	9.81	11.76	13.72	15.68	17.64	19.6	21.56	23.52	25.48	27.44	29.41	31.37	33.33	35.29	37.25	50°
60°			0	1.92	3.84	5 77	7.69	9.61	11.54	13.46	15.38	17.31	19.23	21.15	23.07	25.	26.92	28.84	30.76	32.69	34.61	60°
70°				0	1.88	3.77	5.66	7.54	9.43	11.32	13.21	15.1	16.98	18.87	20.75	22.64	24.52	26.41	28.3	30.18	32.07	70°
80°					0	1.85	3.71	5.55	7.40	9.25	11.11	12.96	14.81	16.66	18.51	20.37	22.22	24.07	25.92	27.77	29.63	80°
90°						0	1.81	3.63	5.45	7.27	9.09	10.9	12.72	14.54	16.36	18.18	20.	21.81	23.63	25.45	27.27	90°
100°							0	1.79	3.57	5.36	7.14	8.93	10.71	12.5	14.28	16.07	17.85	19.64	21.42	23.21	25.	100°
110°								0	1.75	3.51	5.26	7.02	8.78	10.53	12.28	14.04	15.78	17.54	19.30	21.06	22.81	110°
120°									0	1.72	3.45	5.17	6.90	8.62	10.34	12.07	13.79	15.52	17.24	18.97	20.68	120°
130°										0	1.69	3.38	5.08	6.77	8.47	10.17	11.86	13.55	15.25	16.94	18.64	130°
140°											0	1.67	3.33	5.	6.67	8.33	10.	11.67	13.33	15.	16.67	140°
150°												0	1.64	3.28	4.92	6.56	8.20	9.83	11.48	13.11	14.75	150°
160°													0.	1.61	3.23	4.84	6.45	8.06	9.67	11.29	12.9	160°
170°														0	1.59	3.17	4 76	6.35	7.94	9.52	11.11	170°
180°															0	1.56	3.12	4.69	6.25	7.81	9.37	180°
190°																0	1.53	3.08	4.61	6.15	7.69	190°
200°																	0	1.51	3.03	4.54	6.06	200°
210°																		0	1.48	2.98	4.47	210°
220°																			0	1.47	2.94	220°
230°																				0	1.44	230°

Temperature	250°	260°	270°	280°	290°	300°	310°	320°	330°	340°	350°	360°	370°	380°	390°	400°	410°	420°	430°	440°	450°	Temperature
30°	44.89	46.93	48.97	51.02	53.06	55.11	57.14	59.18	61.22	63.26	65.3	67.34	69.38	71.43	73.47	75.51	77.55	79.59	81.63	83.67	85.71	30°
40°	42.	44.	46.	48.	50.	52.	54.	56.	58.	60.	62.	64.	66.	68.	70.	72.	74.	76.	78.	80.	82.	40°
50°	39.21	41.17	43.13	45.09	47.05	49.01	50.98	52.94	54.91	56.86	58.82	60.78	62.74	64.71	66.66	68.62	70.58	72.54	74.51	76.47	78.43	50°
60°	36.53	38.46	40.38	42.31	44.23	46.15	48.07	50.	51.92	53.84	55.76	57.69	59.61	61.53	63.46	65.38	67.31	69.23	71.15	73.07	75.	60°
70°	33.96	35.84	37.73	39.62	41.51	43.39	45.28	47.17	49.05	50.94	52.83	54.71	56.61	58.49	60.37	62.26	64.15	66.03	67.92	69.81	71.71	70°
80°	31.48	33.33	35.18	37.03	38.88	40.74	42.59	44.44	46.29	48.14	50.	51.85	53.71	55.55	57.41	59.25	61.11	62.97	64.81	66.66	68.51	80°
90°	29.09	30.91	32.72	34.54	36.36	38.18	40.	41.81	43.63	45.45	47.27	49.09	50.91	52.72	54.54	56.36	58.18	60.	61.81	63.63	65.45	90°
100°	26.78	28.57	30.35	32.14	33.92	35.71	37.51	39.28	41.07	42.85	44.64	46.42	48.21	50.	51.78	53.57	55.35	57.14	58.92	60.71	62.51	100°
110°	24.56	26.32	28.07	29.82	31.58	33.33	35.09	36.84	38.60	40.35	42.10	43.85	45.61	47.36	49.13	50.88	52.63	54.38	56.14	57.89	59.65	110°
120°	22.41	24.13	25.86	27.58	29.31	31.03	32.75	34.48	36.21	37.92	39.65	41.37	43.11	44.82	46.55	48.27	50.	51.72	53.44	55.17	56.89	120°
130°	20.33	22.03	23.72	25.42	27.11	28.81	30.51	32.21	33.89	35.59	37.28	38.98	40.67	42.37	44.06	45.76	47.45	49.15	50.84	52.54	54.23	130°
140°	18.33	20.	21.66	23.33	25.	26.67	28.33	30.	31.67	33.33	35.	36.67	38.33	40.	41.67	43.33	45.	46.67	48.33	50.	51.67	140°
150°	16.39	18.03	19.67	21.31	22.95	24.59	26.23	27.87	29.51	31.15	32.78	34.42	35.07	37.71	39.34	40.98	42.62	44.26	45.9	47.54	49.18	150°
160°	14.51	16.12	17.74	19.35	20.96	22.58	24.19	25.8	27.41	29.03	30.64	32.25	33.87	35.48	37.09	38.71	40.32	41.93	43.54	45.16	46.77	160°
170°	12.69	14.28	15.87	17.45	19.04	20.63	22.22	23.81	25.39	26.98	28.57	30.15	31.74	33.33	34.91	36.51	38.09	39.68	41.27	42.85	44.44	170°
180°	10.94	12.5	14.06	15.62	17.19	18.75	20.31	21.88	23.44	25.	26.56	28.12	29.69	31.25	32.81	34.38	35.94	37.5	39.06	40.62	42.19	180°
190°	9.23	10.77	12.31	13.85	15.38	16.92	18.46	20.	21.53	23.07	24.61	26.15	27.69	29.23	30.77	32.3	33.84	35.38	36.92	38.46	40.	190°
200°	7.57	9.09	10.6	12.12	13.63	15.15	16.66	18.18	19.69	21.21	22.73	24.24	25.75	27.27	28.78	30.30	31.82	33.33	34.85	36.36	37.87	200°
210°	5.97	7.46	8.95	10.45	11.94	13.43	14.93	16.42	17.01	19.41	20.89	22.39	23.88	25.37	26.86	28.36	29.84	31.34	32.83	34.33	35.87	210°
220°	4.41	5.88	7.35	8.82	10.29	11.77	13.24	14.71	16.18	17.65	19.12	20.58	22.05	23.53	25.	26.47	27.94	29.41	30.88	32.35	33.82	220°
230°	2.89	4.34	5.79	7.23	8.69	10.14	11.59	13.04	14.49	15.94	17.39	18.84	20.28	21.73	23.18	24.63	26.08	27.53	28.98	30.43	31.88	230°
240°	1.42	2.85	4.28	5.71	7.14	8.57	10.	11.42	12.85	14.28	15.71	17.14	18.57	20.	21.42	22.85	24.28	25.71	27.14	28.57	30.	240°
250°	0	1.41	2.81	4.22	5.63	7.04	8.45	9.85	11.20	12.07	14.08	15.49	16.91	18.31	19.71	21.12	22.53	23.94	25.35	26.76	28.17	250°

See Statements with regard to Moist Heating on page 15.

When moist heating is employed, the increase in volume will be about double that in the above Table, which relates to dry air.

TABLE SHOWING THE PERCENTAGE LOSS IN POWER—FROM A FALL IN PRESSURE—DUE TO PIPE FRICTION OR THROTTLING.

To determine the loss, find the *initial* or higher pressure—in the top horizontal line—and the *final* or lower pressure in the right or left hand vertical column; at their intersection the loss of power will be given. "This table refers to gauge pressure only."

Gauge Pressure	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105	110	115	120	125	130	135	140	Gauge Pressure
15	18.11	29.21	36.77	42.27	46.48	49.80	52.55	54.81	56.74	58.40	60.13	61.12	62.25	63.20	64.18	65.04	65.77	66.46	67.10	67.71	68.25	68.77	69.25	69.69	70.13	15
20	0	13.54	22.78	29.50	34.79	38.72	42.05	44.72	47.17	49.10	50.95	52.51	53.9[illegible]	55.14	56.25	57.26	58.20	59.05	59.83	60.65	61.21	61.85	62.44	62.99	63.50	20
25		0	10.67	18.44	24.39	29.11	32.96	36.16	38.90	41.22	43.28	45.07	46.67	48.11	49.40	50.57	51.63	52.63	53.54	54.38	55.16	55.87	56.56	57.19	57.79	25
30			0	8.72	15.37	20.64	24.96	28.55	31.59	34.00	36.49	38.51	40.30	41.91	43.35	44.66	45.86	46.97	47.99	48.93	49.80	50.61	51.37	52.08	52.75	30
35				0	7.30	13.08	17.79	21.73	25.08	27.94	30.45	32.65	34.61	36.37	37.96	39.40	40.64	41.92	43.03	44.06	45.01	45.89	46.73	47.52	48.24	35
40					0	6.24	11.33	15.58	19.17	22.27	24.98	27.36	29.47	31.36	33.08	34.63	36.04	37.34	38.54	39.64	40.68	41.65	42.54	43.38	44.16	40
45						0	5.42	9.95	13.78	17.10	19.98	22.47	24.77	26.79	28.61	30.28	31.78	33.17	34.45	35.64	36.73	37.76	38.71	39.61	40.46	45
50							0	4.79	8.84	12.34	15.37	18.06	20.46	22.59	24.52	26.28	27.87	29.34	30.69	31.94	33.11	34.18	35.34	36.14	37.04	50
55								0	4.26	7.94	11.94	13.94	16.40	18.70	20.73	22.57	24.27	25.78	27.20	28.52	29.74	31.04	31.94	32.93	33.87	55
60									0	3.84	7.18	10.13	12.73	15.08	17.21	19.13	20.88	22.48	23.97	25.34	26.62	27.81	28.91	29.96	30.93	60
65										0	3.49	6.54	9.26	11.72	13.90	15.90	17.72	19.39	20.93	22.38	23.68	24.92	26.09	27.15	28.17	65
70											0	3.13	5.99	8.81	10.68	12.72	14.75	16.49	18.07	19.58	20.95	22.24	23.42	24.54	25.58	70
75												0	2.84	5.52	8.09	10.03	11.98	13.76	15.41	16.93	18.36	19.68	20.91	22.07	23.15	75
80													0	2.69	5.14	7.30	9.33	9.16	12.74	14.39	15.88	17.27	18.55	19.74	20.86	80
85														0	2.50	4.77	6.83	8.74	10.46	12.08	13.58	14.98	16.29	17.53	18.7[illegible]	85
90															0	2.32	4.43	6.39	8.40	9.84	11.35	12.80	14.16	15.41	16.59	90
95																0	2.17	4.17	6.01	7.70	9.26	10.72	12.12	13.40	14.61	95
100																	0	2.03	3.90	5.74	7.13	8.76	10.11	11.47	12.70	100
105																		0	1.91	3.68	5.31	6.87	8.30	9.64	10.90	105
110																			0	1.81	3.49	5.05	6.50	7.77	9.16	110
115																				0	1.72	3.30	4.77	6.17	7.49	115
120																					0	1.63	2.97	4.55	5.88	120
125																						0	1.52	2.97	4.32	125
130																							0	1.46	2.84	130

TABLE SHOWING THE PERCENTAGE LOSS IN POWER—FROM A FALL IN PRESSURE—DUE TO PIPE FRICTION OR THROTTLING.

—CONTINUED—

Gauge Press're	145	150	155	160	165	170	175	180	185	190	195	200	205
15	70.53	70.90	71.24	71.59	71.92	72.22	72.50	72.78	73.04	73.30	73.54	73.78	74.00
20	63.16	64.46	64.89	65.31	65.69	66.06	66.42	66.75	67.07	67.39	67.69	67.97	68.23
25	58.35	58.89	59.39	59.86	60.32	60.75	61.15	61.55	61.92	62.28	62.62	62.95	63.26
30	53.38	53.97	54.54	55.08	55.58	56.06	56.52	56.96	57.37	57.77	58.16	58.52	58.88
35	48.94	49.59	50.21	50.79	51.34	51.88	52.37	52.85	53.31	53.75	54.17	54.58	54.96
40	44.92	45.62	46.29	46.91	47.51	48.08	48.61	49.13	49.64	50.11	50.56	51.00	51.41
45	41.25	42.01	42.71	43.38	44.01	44.62	45.21	45.75	46.26	46.79	47.27	47.74	48.18
50	37.87	38.66	39.57	40.13	40.80	41.45	42.06	42.64	43.20	43.73	44.24	44.73	45.21
55	34.76	35.58	36.40	37.12	37.82	38.51	39.14	39.76	40.34	40.91	41.44	41.97	42.46
60	31.84	32.71	33.55	34.33	35.06	35.77	36.44	37.08	37.69	38.27	38.84	39.39	39.90
65	29.14	30.05	30.90	31.71	32.47	33.21	33.93	34.57	35.21	35.82	36.40	36.96	37.50
70	26.59	27.53	28.40	29.24	30.03	30.80	31.52	32.21	32.97	33.51	34.11	34.69	35.27
75	24.18	25.15	26.08	26.93	27.76	28.55	29.29	30.00	30.67	31.32	31.95	32.55	33.05
80	21.91	22.91	23.85	24.74	25.60	26.40	27.20	27.95	28.59	29.27	29.91	30.53	31.11
85	19.76	20.77	21.75	22.66	23.53	24.37	25.15	25.91	26.64	27.32	27.98	28.61	29.22
90	17.70	18.75	19.74	20.68	21.59	22.43	23.24	24.02	24.75	25.46	26.14	26.79	27.41
95	15.74	16.82	17.83	18.79	19.72	20.59	21.43	22.22	22.97	23.68	24.39	25.04	25.68
100	13.88	14.98	16.01	16.99	17.92	18.83	19.66	20.42	21.26	22.00	22.71	23.30	24.03
105	12.08	13.20	14.28	15.28	16.23	17.15	18.00	18.83	19.63	20.36	21.09	21.79	22.46
110	10.38	11.51	12.60	13.62	14.59	15.53	16.42	17.25	18.06	18.93	19.56	20.27	20.95
115	8.72	9.88	11.00	12.04	13.02	13.96	14.87	15.72	16.53	17.32	18.07	18.79	19.48
120	7.15	8.32	9.45	10.60	11.51	12.48	13.38	14.26	15.11	15.90	16.65	17.40	18.09
125	5.61	6.81	7.95	9.03	10.03	11.04	11.96	12.84	13.70	14.51	15.28	16.03	16.74
130	4.12	5.36	6.52	7.61	8.65	9.65	10.59	11.49	12.30	13.16	13.96	14.73	15.43

Gauge Press're	210	215	220	225	250	275	300	350	400	500	1000	2000	Gauge Press're
15	74.22	74.42	74.62	74.81	75.67	76.41	77.05	78.10	78.94	80.22	83.39	85.71	15
20	68.50	68.76	69.00	69.23	70.92	71.19	71.97	73.25	74.28	75.85	79.71	82.54	20
25	63.55	63.86	64.14	64.42	65.63	66.67	67.57	69.06	70.25	72.06	76.54	79.81	25
30	59.21	59.54	59.85	60.16	61.53	62.69	63.71	65.37	66.70	68.73	73.74	77.40	30
35	55.33	55.69	56.04	56.36	57.86	59.14	60.24	62.07	63.52	65.74	71.23	75.24	35
40	51.82	52.21	52.58	52.94	54.55	55.92	57.12	59.08	60.66	63.04	68.97	73.35	40
45	48.60	49.02	49.42	49.80	51.51	52.99	54.26	56.36	58.03	60.58	66.90	71.52	45
50	45.66	46.08	46.50	46.91	48.74	50.28	51.52	53.86	55.63	58.32	65.01	69.89	50
55	42.93	43.39	43.83	44.24	46.15	47.80	49.10	51.54	53.40	56.23	63.24	68.36	55
60	40.39	40.86	41.33	41.76	43.77	45.46	46.93	49.38	51.33	54.28	61.71	66.96	60
65	38.03	38.51	39.02	39.46	41.52	43.30	44.83	47.36	49.38	52.47	60.10	65.64	65
70	35.78	36.19	36.78	36.98	39.43	41.25	42.84	45.44	47.58	50.75	58.65	64.4	70
75	33.67	34.21	34.72	35.21	36.00	39.33	40.97	43.68	45.84	49.13	57.29	63.24	75
80	31.69	32.24	32.77	33.29	35.57	37.52	39.20	41.99	44.22	47.60	56.01	62.14	80
85	29.80	30.37	30.90	31.42	33.76	35.79	37.52	40.39	42.68	46.16	54.79	61.10	85
90	28.01	28.58	29.14	29.67	32.10	34.11	35.93	38.87	41.21	44.79	53.64	60.10	90
95	26.30	26.87	27.46	28.01	30.47	32.58	34.40	37.41	39.81	43.48	52.54	59.16	95
100	24.66	25.27	25.85	26.42	28.92	31.08	32.95	36.03	38.48	42.21	51.48	58.24	100
105	23.10	23.70	24.30	24.87	27.46	29.64	31.55	34.70	37.21	41.02	50.48	57.41	105
110	21.61	22.24	22.82	23.40	26.04	28.29	30.21	33.42	35.99	39.87	49.51	56.55	110
115	20.14	20.79	21.43	22.00	24.68	26.95	28.92	32.19	34.81	38.76	48.59	55.75	115
120	18.77	19.42	20.03	20.64	23.37	25.70	27.69	31.02	33.67	37.70	47.70	54.98	120
125	17.44	18.07	18.73	19.33	22.11	24.47	26.52	29.80	32.58	36.67	46.82	54.24	125
130	16.13	16.80	17.46	18.07	20.89	23.28	25.36	28.78	31.53	35.69	46.00	53.53	130

TABLE SHOWING THE PERCENTAGE LOSS IN POWER—FROM A FALL IN PRESSURE—DUE TO PIPE FRICTION OR THROTTLING.

—CONTINUED—

Gauge Press're	140	145	150	155	160	165	170	175	180	185	190	195	200	205	210	215	220	225	250	275	300	350	400	500	1000	2000.	Gauge Press're
135	1.40	2.71	3.95	5.14	6.24	7.30	8.30	9.26	10.38	11.04	11.88	12.68	13.44	14.18	14.91	15.52	16.23	16.86	19.72	22.15	24.25	27.74	30.51	34.73	45.20	52.83	135
140	0	1.32	2.60	3.80	4.92	5.99	6.90	7.98	8.96	9.78	10.63	11.45	12.22	12.96	13.68	14.37	15.06	15.69	18.59	21.04	23.17	26.70	29.53	33.81	44.42	52.17	140
145		0	1.28	2.48	3.64	4.68	5.74	6.74	7.68	8.57	9.43	10.26	11.04	11.80	12.52	13.22	13.90	14.55	17.48	19.98	22.15	25.71	28.56	32.92	43.67	51.51	145
150			0	1.21	2.39	3.49	4.52	5.52	6.47	7.38	8.25	9.10	9.88	10.65	11.39	12.10	12.78	13.44	16.42	18.94	21.14	24.75	27.65	32.05	42.94	50.90	150
155				0	1.17	2.30	3.35	4.37	5.31	6.24	7.13	7.96	8.78	9.56	10.29	11.02	11.72	12.38	15.37	17.94	20.16	23.83	26.76	31.21	42.24	50.28	155
160					0	1.12	2.21	3.21	4.19	5.14	6.03	6.87	7.70	8.48	9.24	9.86	10.65	11.33	14.37	16.99	19.24	22.93	25.89	30.39	41.55	49.70	160
165						0	1.07	2.12	3.10	4.04	4.94	5.81	6.63	7.42	8.19	8.93	9.65	10.31	13.40	16.01	18.28	22.04	25.04	29.59	40.88	49.12	165
170							0	1.05	2.05	2.90	3.90	4.79	5.61	6.42	7.10	7.04	8.65	9.35	12.44	15.11	17.40	21.10	24.22	28.83	40.23	48.56	170
175								0	1.00	1.96	2.88	3.77	4.61	5.44	6.22	6.95	7.68	8.38	11.53	14.20	16.51	20.34	23.42	28.07	39.61	48.02	175
180									0	.96	1.89	2.70	3.64	4.48	5.27	6.01	6.74	7.45	10.63	13.32	15.67	19.56	22.64	27.34	39.99	47.50	180
185										0	.94	1.85	2.71	3.53	4.32	5.00	5.83	6.33	9.74	12.48	14.85	19.75	21.88	26.64	38.38	46.97	185
190											0	.92	1.78	2.62	3.42	4.19	4.94	5.66	8.91	11.65	14.04	17.98	21.14	25.94	37.80	46.47	190
195												0	.87	1.74	2.55	3.30	4.06	4.79	8.06	10.85	13.24	17.25	20.42	25.26	37.24	45.95	195
200													0	.85	1.67	2.46	3.21	3.95	7.26	10.05	12.48	16.49	19.72	24.49	36.69	45.50	200
205														0	.83	1.63	2.39	3.13	6.46	9.28	11.74	15.78	19.02	23.95	36.13	45.04	205
210															0	.81	1.58	2.55	5.66	8.53	11.00	14.91	18.34	23.32	35.61	44.57	210
215																0	.78	1.53	4.92	7.79	10.27	14.39	17.69	22.69	30.59	44.12	215
220																	0	.76	4.17	7.06	9.58	13.74	17.06	22.09	34.58	43.6[illegible]	220
225																		0	3.42	6.35	8.89	13.06	16.44	21.50	34.08	43.28	225
250																			0	3.04	5.66	9.99	13.44	18.70	31.74	41.2[illegible]	250
275																				0	2.71	7.17	10.72	16.17	29.59	39.41	275
300																					0	4.59	8.25	14.04	27.65	37.68	300
350																						0	3.84	9.67	24.16	34.73	350
400																							0	6.07	21.14	32.13	400
500																								0	16.03	27.74	500
1000																									0	13.94	1000
																										0	